# BEHAVIOR OF THE COMMON ROACH (PERIPLANETA ORIENTALIS L.) ON AN OPEN MAZE.

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## TECHNIQUE.

The maze (Fig. 1) used in these experiments was constructed out of a sheet of copper 13.5 inches long and twelve inches wide. Each runway is one inch wide and has neither sides nor top; and between each adjacent runway there is a space one and a half inches wide. This maze contains four blind alleys; two which are straight (Fig. 1, *A*, *B*), one which is L-shaped (Fig. 1, 8 *DE*), and one which bears three culdesacs (Fig. 1, 9 10 11

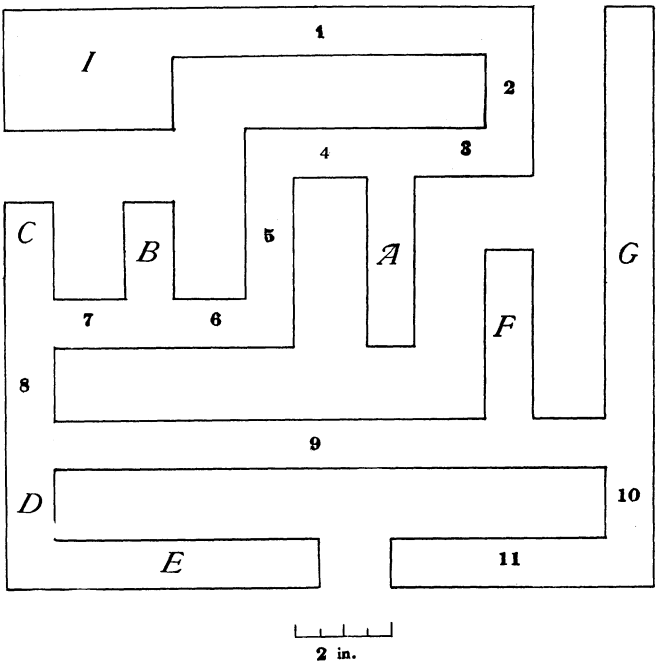


FIG. 1. A diagram of the maze used. *I* is the platform on which the roach is placed. *C* is the point from which the incline departs. The numerals 1–7 indicate the direct passageway to *C*. *A* is blind alley I., *B* is blind alley II., 8 *DE* is blind alley III. and 9 *FG* 10 11 is blind alley IV. of the tables.

*FG*). When in use the maze is supported, in a horizontal position, by glass pillars which rest in wide pans of water (Fig. 2). These pillars were made by inserting glass stirring rods in the corks of wide-mouth bottles. When thus supported, the maze was about eight inches above the surface of the water which extended beyond it, in all directions, to a distance of eight to twenty inches. To facilitate the taking of accurate notes the parts of the stage were labeled as indicated in Fig. 1.

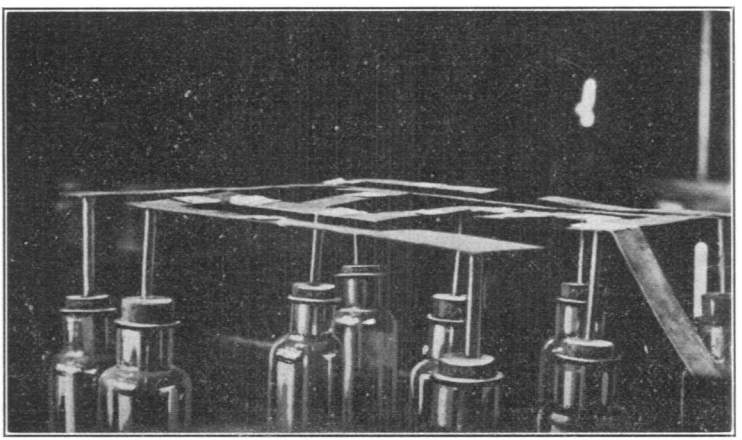

FIG. 2. Photo showing the maze and the upper portions of its support as arranged for use.

These experiments were conducted, in the summer time, in an out-of-doors insectary, the whole north wall of which, except a narrow strip for a door, was constructed of wire netting. The three other walls were without either windows or doors, hence this north opening was the only source of light. Except in the few special cases mentioned in the body of this article, the maze was always arranged with the side *I*1 on the north and parallel to that side of the house.

As originally planned the experiments were to test the ability of the roach to learn to go by the shortest route from the portion of the maze marked "*I*" to a dark box placed at some definite place on the maze. A few preliminary experiments demonstrated that the box did not make a satisfactory goal. Some insects on reaching the box would enter it and remain therein; others would

climb up to the top of it, meander around and then descend and go to some other part of the maze. Hence a cardboard incline, extending from some definite part of the maze to the jelly glass that had served as a cage for the roach, was substituted for the dark box.

This same series of experiments taught me that the best place for the incline to leave the maze was the point labeled "*C*." To be of value the incline should be located where the roach, in roaming about the maze, is sure to accidentally discover it. It was found that, in almost all cases, a roach, on reaching the junction of 7, *C* and 8, turned into 8 and, after passing into *D* and often into *E*, retraced its steps and entered *C*; hence an incline placed at *E* would have been too easy a problem. It was noticed that roaches seldom entered 9; hence to place the incline at the extremity of either 11 or *G* would be making the task too difficult. *C* seemed the golden mean.

The roaches used as the subjects of these experiments were isolated in jelly glasses and given an abundance of food. No roach was used in an experiment until it had been in its jelly-glass cage for several days. This was done to get the roach accustomed to confinement and to my presence. The roaches used were females varying in size from young ones ten millimeters in length to full-grown individuals.

The roach to be tested was always placed on *I*. This was done in two different ways. Sometimes the hind leg of a roach was grasped in a pair of forceps and the roach placed on *I*; at others, by means of forceps, the roach was transferred from its glass cage to a narrow cylindrical beaker. This glass was then covered with a small piece of paper and the whole inverted on the maze at *I*. The paper was then removed, and, as soon as the roach quieted down, the cylindrical glass was removed. If a roach ran the maze three times in succession without making an error, it was considered to have solved it. After each trial, the surface and the edges of the maze were painted with alcohol to remove any odor that might have been deposited by the roach.

For convenience, the errors made were grouped under two heads: those which resulted in the roach falling into the water and those made by the roach while remaining on the maze.

Under the first head there are three subdivisions: (1) rushes into the water without attempting to run the maze, (2) falls into the water after the roach had begun to run the maze, and (3) jumps into the water. Under the second head there are two subdivisions: (1) entering blind alleys, and (2) moving in the wrong

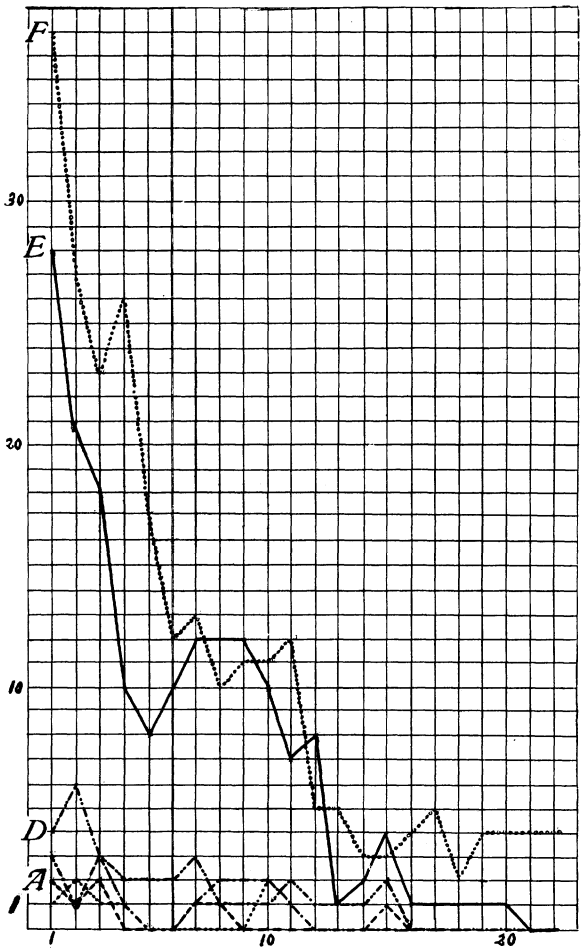


FIG. 3. Learning curves constructed from the average reactions of ten roaches. The spaces from right to left represent successive trials. *A*, the number of times the roach rushed into the water before beginning to run the maze. *B*, the number of times the roach fell into the water after beginning to run the maze. *C*, the number of times the roach jumped into the water. *D*, the total number of times the roach entered blind alleys. *E*, total number of errors made. *F*, total minutes required to run the maze.

direction along the right path. From the time the roach entered a blind alley until it returned to the right path was counted one error. If a roach which was moving in the wrong direction along the right path paused from time to time, each movement after a pause was counted an error. Movements, other than dashes into the water, which were made by a roach on *I* before it had entered the runway 1 were not counted; but once the roach had entered the runway 1, even though it returned to the starting platform *I*, all incorrect movements made by it were counted errors.

In my first experiments I arranged for the successive trials of each roach to come at intervals of several hours. This was done because I had an idea that experiments conducted at short intervals would produce fatigue effects which would vitiate the work. However, I soon found that the best results were obtained where the successive trials came at intervals of about half an hour and were continued throughout the working hours of a day. Towards the end of a long hot day such fatigue effects as a pronounced slowness of movement and the lapsing into errors that the roach had formed the habit of omitting would appear; but, on the whole, the repetition of trials at short intervals was much more satisfactory than the other method of experimenting.

## Discussion of the Experiments.

Upon being placed on the maze for the first time, a roach almost invariably rushes off into the water. Upon being replaced on the maze, it usually repeats the performance; some, however, do not rush into the water a second time. Sooner or later it stops rushing into the water and begins to move around in search of some other means of escape. It moves to and fro along the runways, if paths with neither sides nor top may be called runways, enters blind alleys, occasionally falls into the water,[1] makes its toilet one or more times, perhaps engages in a few acrobatic stunts, and finally, by accident, discovers the incline and passes down it to the glass cell that is its home. The first time the roach is placed on the stage, this performance

[1] After it had fallen into the water, the roach was always replaced on the maze at the place from which it had its fall.

consumes from fifteen to sixty minutes. The next few trials the roach behaves in practically the same manner, but makes fewer and fewer mistakes. Finally, after a prolonged series of trials, in spite of frequent lapses, the mistakes are gradually eliminated and the roach runs the maze, without making any errors, in from one to four minutes. As the roach moves along, the antennæ are waving almost incessantly, as though seeking stimuli. The mistakes are eliminated so gradually that this may be considered a trial and error type of learning, if one may use that expression without predicating the absence of sensations and feelings. Such, in brief, is the behavior of the common roach on the maze; but one is impressed by the variations displayed.

These variations in behavior are of two types: differences due to age and modifications due to individuality. The older roaches usually move much more slowly and much more carefully than the younger ones. Roaches from ten to twelve millimeters long usually move so rapidly that they might well be called frisky. The slower gait of the older roaches is not due to feebleness, for they are fleet enough when placed on the floor of a room; but to what, in human beings, we call caution. As a result of this difference in speed, the younger roaches, on their initial trial, usually run the maze much more quickly than the adults; but, in doing so, make many more mistakes.

The variations due to individuality are the ones that are especially impressive. Some roaches, with humped backs, move sedately along in the middle of the runways, pausing at each corner to explore upward, outward and downward with their antennæ; others trot along in the middle of the runways, at first usually falling into the water at each angle, but later slowing up at the corners, exploring with their antennæ and moving onward. Some roaches, with their bodies extended until they are practically flat, drag themselves along so slowly that it taxes the patience of anyone who happens to be watching them; others, moving sometimes slowly and sometimes rapidly, always keep the claws of the legs of one side of the body in contact with the edge of the runway. When such a roach turns a corner it usually, although not invariably, crosses to the opposite side of the runway and clings to the edge with the legs of the corre-

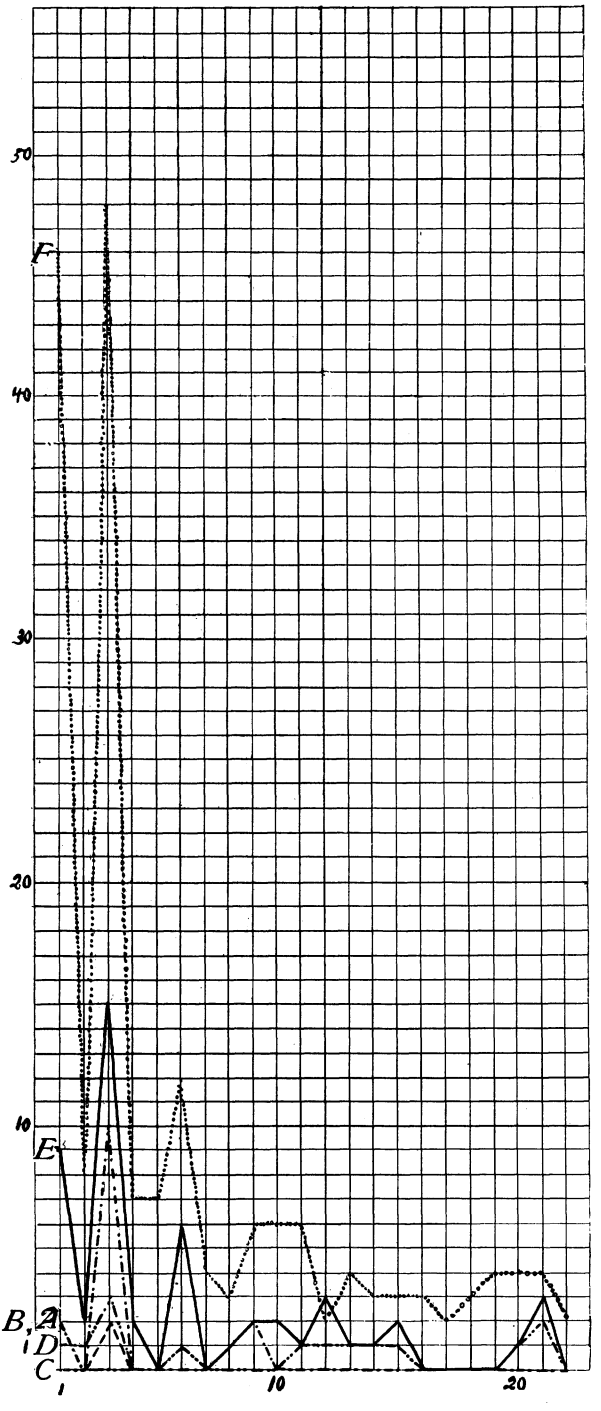


FIG. 4. Learning curves of a female roach 17 mm. long. The spaces from right to left represent successive trials. *A*, the number of times the roach rushed into the water before beginning to run the maze. *B*, the number of times the roach fell into the water after beginning to run the maze. *C*, the number of times the roach jumped into the water. *D*, the total number of times the roach entered blind alleys. *E*, total number of errors made. *F*, total minutes required to run the maze.

sponding side of its body. Some roaches pause at practically every point on the side of the runways and explore upward, outward, and downward with their antennæ, and then, retracing their steps, explore the same territory over and over again; yet other roaches pause only here and there to make explorations. Some roaches, and this is especially true of roaches from ten to fifteen millimeters in length, move along part of the time on top of the maze and part of the time suspended from its edge. Had the maze been constructed of cardboard these same roaches would have made part of their journey suspended from the bottom of the maze. Some roaches pause from time to time to make their toilet; others never once pause for such purposes. Some few roaches, after making several attempts to find an exit from the maze, stop trying and act as though they have given up all hope of succeeding; others, after failing to find a means of escape, attempt to jump to freedom. These jumping roaches were always returned to the maze at the point from which they jumped. After one to many jumps had proved failures, these roaches usually stopped jumping and proceeded to solve the maze in the right way. These variations were not inflexible instinctive responses, for the same roach did not always behave the same way at all trials.

### Jumping Activities and Will.

Although this jumping activity results in a plunge into the water, it resembles neither the dashes into the water made by a roach on being placed on the maze for the first time nor the falls into the water by roaches that are trying to run the maze. The roach pauses at the edge of the maze and explores outward and downward with its antennæ. It acts as though it were trying to see something at a distance and then, after a pause, makes what an athlete would call a broad jump. Many roaches displayed this jumping behavior, but some were more prone to jump than others. I experimented with one roach which, on its initial trial, made ten jumps from the maze; usually from a different point each time. This jumping attitude is so characteristic that one can always predict when a roach is likely to jump. I say likely to jump instead of going to jump; because, after a roach has once

jumped into the water, the jumping attitude does not always result in a spring. To see a roach, which has learned to avoid rushing off of the maze into the water and which will struggle hard to avoid slipping from the edge of a runway into the water, halt, reach outward and upward with its antennæ, act as though it were trying to see what is beyond, pause and then jump is food for much thought. Have we not here a conflict of impulses and is not the jumping or the refusing to jump the resultant of this conflict? Is not such a resultant what the human psychologists call an act of will? Whenever I behold the jumping behavior, I am impressed with a feeling that the roach is experiencing a conflict of impulses and hence is displaying a will.

In most cases the jumps were made from some one of the outer edges of the maze; but, in a few cases, the jump seemed to be aimed at a definite point. On two occasions a roach jumped and landed on the cork of one of the bottles that supported the maze. At another time, a roach jumped from the runway 2 to blind alley *G* and traveled along that, over zigzaging pathways, to the main trail at *C* and thence to the incline and down it to its cell. On its next trial, the roach attempted to make this same leap; but only its forefeet touched *G* and it fell into the water. On two other occasions I noticed roaches attempt to jump from one runway to another; but they always failed to secure a foothold.

## Acrobatic Feats.

The broad jumps described above are not the only acrobatic activities of the roaches that ran the maze. As mentioned above, the roaches frequently moved along suspended from the edge of a runway. With the three feet of one side clinging to the edge of the maze and with the three feet of the other side braced against the under side of the runway, any of the roaches could progress for a short distance, and the young roaches, those from ten to twelve millimeters in length, would run along in this position and return to the upper side at pleasure. In this inverted position, the young roaches could even turn around without returning to the upper side of the runway. Letting go of the edge of the maze with the first and second feet of the off side and catching hold of the edge with the third foot of the

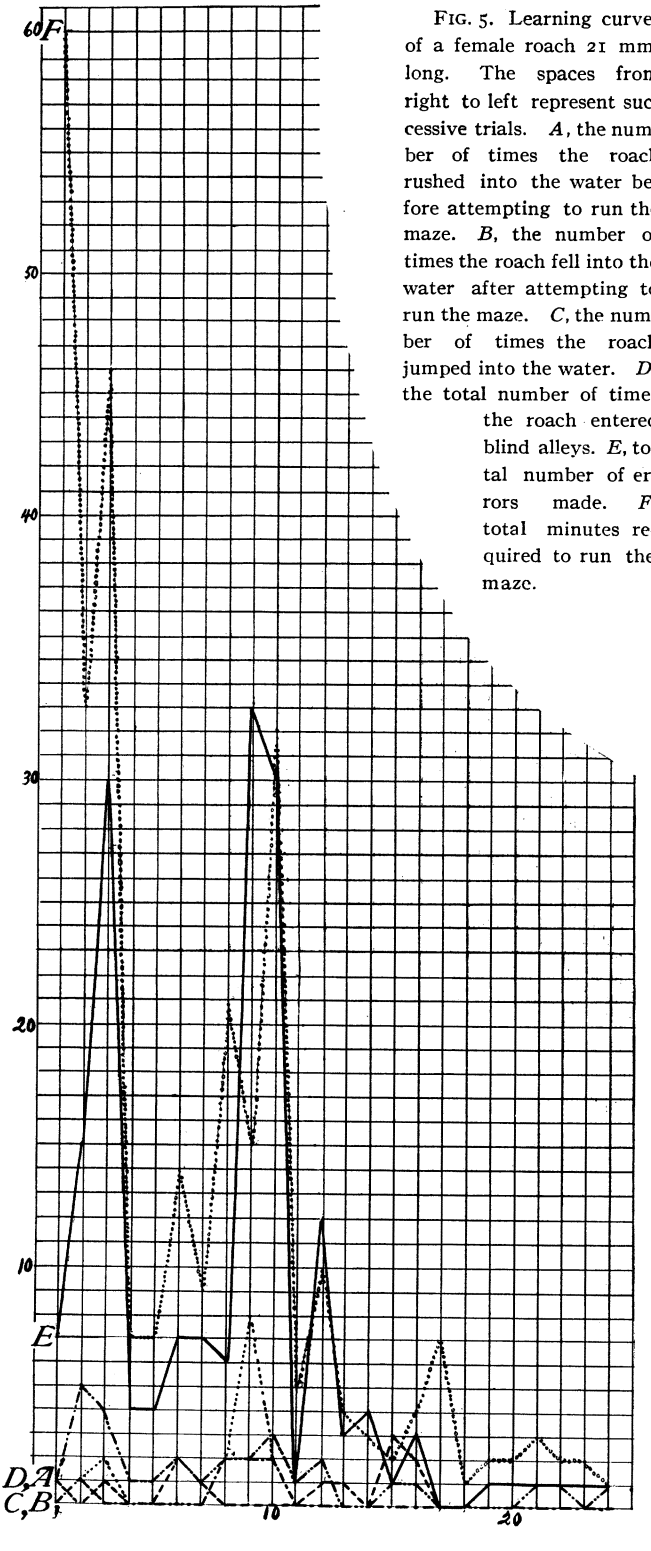


FIG. 5. Learning curves of a female roach 21 mm. long. The spaces from right to left represent successive trials. *A*, the number of times the roach rushed into the water before attempting to run the maze. *B*, the number of times the roach fell into the water after attempting to run the maze. *C*, the number of times the roach jumped into the water. *D*, the total number of times the roach entered blind alleys. *E*, total number of errors made. *F*, total minutes required to run the maze.

inner side, the roach would swing around on the underside of the maze until it could catch hold of the edge with the first and second feet of what had been the inner side. It then would remove the third foot of what had been the outer side and move along in the opposite direction. It was a common thing for roaches ten to twelve millimeters long to rest suspended beneath the maze with the claws of the third pair of legs clinging to the edge of a runway and with the other feet braced against its undersurface.

Frequently a roach was noticed making its toilet while suspended from the maze by one foot. On one occasion I observed a roach, about seventeen millimeters long, which was hanging suspended from the maze by its right third leg, brace itself by bringing the left third leg in front of the other and clinging to the edge of the maze with both feet.

## Toilet-Making Habits.

I stated above that frequently movements to solve the maze are interrupted by toilet-making activities. Since most people look upon roaches as nasty things, this toilet-making behavior is a surprisingly interesting instinct. The mouth-parts, the first pair of legs and the third pair of legs are the instruments used by the roach in making its toilet and each has its special work. In cleaning the head and the base of the antennæ the first pair of legs are used in much the same way that a cat uses her forelegs in washing her face. One of the flexed legs is rubbed downward over the head and the base of the antennæ one or more times and then cleaned by the mouth-parts. This may be repeated several times.

As would be naturally expected, the antennæ, which seem to be the most important sense organs of the roach, are cleaned oftener than any other part. If you are standing a short distance from a roach that is resting on the maze, you will notice an antenna suddenly bend downward into the mouth. Slowly it straightens itself while the constantly moving mouth-parts remove the dirt. The next moment the antenna of the other side suddenly bends downward and is treated in the same way. One day a rather keen observer, who was visiting my insectary,

was sitting about a yard from a roach that was making her toilet. Suddenly he exclaimed: "What powerful muscles those slender antennæ must contain." Those antennæ do contain muscles which are used in waving them in search of stimuli; but those muscles are far too weak to bend the antennæ into the mouth of the roach. Had that visitor looked a little more keenly he would have seen the roach bow its head, dart one of its forelegs forward, catch in its bend the antenna of the other side and bend it downward to the mouth.

Sometimes, after a plunge into water, the antennæ become so wet that they are held together by capillary attraction and extend forward and upward like the horn of a unicorn. In that position they are out of the range of both of the forelegs. It is interesting to watch the energetic and unavailing efforts of such a roach to clean its antennæ. Standing on its second and third legs with the front part of the body elevated, it moves first one foreleg and then the other after the antennæ in such rapid succession that it resembles a gymnast taking arm exercises.

The palps of the maxillæ and of the labium are cleaned by the mouth-parts; but each palp is flexed into the mouth by its own muscles.

The body assumes a characteristic attitude while the legs and the ventral side of the body are being cleaned by the mouth-parts. Supported by the three legs of one side and by the hind leg of the other, the roach, with the side supported by one leg elevated at the expense of the other, reaches underneath her body and gives her legs and it a good cleaning with her mouth-parts. Again one is reminded of the behavior of a cat making her toilet.

To clean the dorsal surface of the abdomen, the roach uses first one hind leg and then the other as a scraper or brush. With these same legs the cercopods are thoroughly cleaned. In this cleaning process the spines on the legs are quite serviceable.

## SENSATIONS.

Plans have been formed to test rather thoroughly the senses of the roach; but, since it will be a long time before the tests can be completed, it is thought best to publish the following preliminary account.

*Tactile.*—The tactile sense of the roach is remarkably keen. Even a slight jar to one portion of the maze is responded to by a sudden more or less prolonged halt on the part of the roach on a distant point on the maze; and this is true when neither antennæ nor palpi are touching the maze and even when the antennæ have been amputated.

*Olfactory.*—On the maze itself no conclusive evidence was obtained of the use of this sense. True the antennæ were almost continually waving in space, but it was impossible to determine whether they were seeking olfactory or tactile stimuli. The trap used in capturing the roaches for these experiments was similar to the Graham roach trap described by F. L. Washburn in the *Journal of Economic Entomology* for June, 1913; but I used an eight-ounce bottle instead of an Erlenmeyer flask and no hairs were placed around the apex of the smaller cone. A trap baited with dry oatmeal flakes would capture practically no roaches; but one baited with oatmeal steeped in stale beer invariably captured large numbers. It seems reasonable to assume that it was the sense of smell that enticed the roaches into the trap.

*Auditory.*—Up to now my notes on the auditory sense are exceptionally non-committal. On the maze roaches seem to pay no attention to sounds produced continuously. For example, a loudly ticking clock was placed two feet from the maze; but to its sounds the roaches made no responses whatever. To certain suddenly produced sounds they responded by halting suddenly, to others they made no response. For example: one day while some tinners were fixing the guttering of a nearby house, to certain noises made by the tin the roaches were quite responsive; but, when, by means of a small bell, I attempted to demonstrate that they respond to suddenly produced sounds, the roaches made absolutely no external responses. By means of a Galton whistle and other methods an attempt is being made to solve the problem; but, up to now, no satisfactory solution has been reached.

*Vision.*—That the roach possesses vision of some kind is certain, and at times a roach would act as though it were able to distinguish objects at a distance. Recall roaches jumping from one runway to another—a distance of an inch and a half—

and roaches jumping from the maze to the top of a nearby bottle. Yet I could bring a pencil to within a centimeter of the head of a roach without causing a response unless I touched one of the antennæ.

## CONCLUSIONS.

1. By arranging the trials at intervals of half an hour, a roach may be taught, within a day, to run the maze.

2. The gradual manner in which it eliminates its errors would cause one to say the roach learns to run the maze by the trial and error method; yet, in so doing, it utilizes sense stimuli. This is evidenced by the careful manner in which it examines (often over and over again) the corners and edges of the maze and the space adjacent thereto.

3. At times the roach acts as though experiencing the emotion the psychologists call will.

4. Although the effects of training persist for a long time, yet the memory of the roach is poor; for after an interval of twelve hours marked lapses were noticed.

5. In its toilet-making activities the behavior of the roach resembles very much the toilet-making activities of the cat.

6. In their behavior on the maze roaches display marked individuality.

## TABLE I.

| Successive Trials. | Date. | Number of Hours that Have Elapsed Since the Beginning of the Last Trial. | Errors Due to Movements on the Maze. | | | | | | Errors which Caused the Roach to Fall into the Water. | | | | Number of Times it Stopped to Make its Toilet. | Total Minutes Required to Run the Maze. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | By Entering Blind Alleys. | | | | Movements in the Right Path, but in the Wrong Direction. | Total. | The Number of Times it Rushed into the Water before Beginning to Run the Maze. | The Number of Times it Fell into the Water After Beginning to Run the Maze. | The Number of Times it Jumped into the Water. | Total. | | |
| | | | I. (Fig. 1, *A*.) | II. (Fig. 1, *B*.) | III. (Fig. 1; 8, *D*, *E*.) | IV. (Fig. 1; 9, 10, 11, *F*, *G*.) | | | | | | | | |
| 1 | Aug. 7, 3:55 P.M. | 0 | 0 | 0 | 1 | 0 | 5 | 6 | 1 | 0 | 0 | 1 | 19 | 60 |
| 2 | Aug. 8, 8:02 A.M. | 16¼ | 3 | 0 | 1 | 1 | 13 | 18 | 0 | 1 | 1 | 2 | 24 | 33 |
| 3 | Aug. 9, 6:54 A.M. | 23 | 3 | 0 | 0 | 0 | 24 | 27 | 1 | 0 | 2 | 3 | 24 | 46 |
| 4 | Aug. 10, 8:08 A.M. | 24¼ | 0 | 0 | 1 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 7 |
| 5 | Aug. 10, 6:53 P.M. | 10¾ | 1 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 1 | 7 |
| 6 | Aug. 11, 7:52 A.M. | 13 | 1 | 0 | 1 | 0 | 3 | 5 | 2 | 0 | 0 | 2 | 8 | 14 |
| 7 | Aug. 11, 2:05 P.M. | 6¼ | 0 | 0 | 1 | 0 | 5 | 6 | 1 | 0 | 0 | 1 | 4 | 9 |
| 8 | Aug. 11, 3:22 P.M. | 1¼ | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 2 | 2 | 4 | 10 | 21 |
| 9 | Aug. 12, 7:23 A.M. | 16 | 1 | 1 | 0 | 0 | 15 | 17 | 0 | 8 | 8 | 16 | 4 | 15 |
| 10 | Aug. 12, 8:06 A.M. | ½ | 2 | 0 | 1 | 0 | 23 | 26 | 0 | 2 | 2 | 4 | 9 | 32 |
| 11 | Aug. 12, 9:16 A.M. | 1¼ | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| 12 | Aug. 12, 10:18 A.M. | 1 | 1 | 1 | 0 | 0 | 7 | 9 | 1 | 0 | 1 | 2 | 3 | 10 |
| 13 | Aug. 12, 12:46 P.M. | 2½ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 2 | 4 | 4 |
| 14 | Aug. 12, 12:54 P.M. | ¼ | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 2 | 3 |
| 15 | Aug. 12, 1:20 P.M. | ½ | 0 | 0 | 1 | 0 | 0 | 1 | 3 | 0 | 0 | 3 | 4 | 2 |
| 16 | Aug. 12, 1:33 P.M. | ¼ | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 2 | 4 |
| 17 | Aug. 12, 2:29 P.M. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 7 |
| 18 | Aug. 12, 2:58 P.M. | ½ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 |
| 19 | Aug. 12, 3:34 P.M. | ½ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 2 |
| 20 | Aug. 12, 4:01 P.M. | ½ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 2 |
| 21 | Aug. 13, 6:04 A.M. | 14 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 3 |
| 22 | Aug. 13, 6:45 A.M. | ¾ | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| 23 | Aug. 13, 7:08 A.M. | ½ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 24 | Aug. 13, 8:03 A.M. | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

This is a compilation of the reactions of the first ten roaches examined. Throughout the first part of this series of experiments a long rest was given after each trial.

## TABLE II.

| Successive Trials. | Date. | Number of Hours that Have Elapsed Since the Beginning of the Last Trial. | Errors Due to Movements on the Maze. | | | | | | Errors which Caused the Roach to Fall into the Water. | | | | Number of Times it Stopped to Make its Toilet. | Total Minutes Required to Run the Maze. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | By Entering Blind Alleys. | | | | Movements in the Right Path, but in the Wrong Direction. | Total. | Number of Times it Rushed into the Water Before Attempting to Run the Maze. | Number of Falls into the Water After Beginning to Run the Maze. | Number of Jumps into the Water. | Total. | | |
| | | | I. (Fig. 1, *A*.) | II. (Fig. 1, *B*.) | III. (Fig. 1: 8, *D*, *E*.) | IV. (Fig. 1; 9, 10, 11, *F*, *G*.) | | | | | | | | |
| 1 | Aug. 8, 9:30 A.M. | 0 | 1 | 0 | 1 | 1 | 0 | 3 | 2 | 10 | 0 | 12 | 13 | 45 |
| 2 | Aug. 14, 5:46 A.M. | 130¼ | 1 | 0 | 0 | 0 | 4 | 5 | 2 | 2 | 0 | 4 | 9 | 48 |
| 3 | Aug. 14, 7:04 A.M. | 1¼ | 0 | 0 | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 8 |
| 4 | Aug. 14, 7:31 A.M. | ½ | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 7 |
| 5 | Aug. 14, 8:03 A.M. | ½ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 6 | Aug. 14, 8:40 A.M. | ½ | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 5 | 0 | 5 | 4 | 12 |
| 7 | Aug. 14, 9:02 A.M. | ¼ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 |
| 8 | Aug. 14, 9:37 A.M. | ½ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 3 |
| 9 | Aug. 14, 10:14 A.M. | ¾ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 6 |
| 10 | Aug. 14, 10:42 A.M. | ½ | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 3 | 6 |
| 11 | Aug. 14, 11:18 A.M. | ½ | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 6 |
| 12 | Aug. 14, 11:45 A.M. | ½ | 1 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 |
| 13 | Aug. 14, 12:16 P.M. | ½ | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 4 |
| 14 | Aug. 14, 12:46 P.M. | ½ | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 3 |
| 15 | Aug. 14, 1:08 P.M. | ½ | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 3 |
| 16 | Aug. 14, 1:58 P.M. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| 17 | Aug. 14, 2:28 P.M. | ½ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 18 | Aug. 14, 3:07 P.M. | ½ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 3 |
| 19 | Aug. 14, 3:50 P.M. | ¾ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 |
| 20 | Aug. 14, 4:24 P.M. | ½ | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 4 |
| 21 | Aug. 15, 5:30 A.M. | 13 | 1 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 1 | 2 | 4 |
| 22 | Aug. 15, 5:46 A.M. | ¼ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 23 | Aug. 16, 6:35 A.M. | 24¾ | 0 | 1 | 0 | 0 | 0 | 1 | 6 | 0 | 0 | 6 | 2 | 12 |

This table records the reactions of a female roach 21 mm. long. Throughout this series of experiments the rest period between the experiments was short.

## TABLE III.

| Successive Trials. | Number of Hours that Have Elapsed Since the Beginning of the Last Trial. | Errors Due to Movements on the Maze. | | | | | | Errors which Caused the Roach to Fall into the Water. | | | | The Number of Times it Stopped to Make its Toilet. | Total Minutes Required to Run the Maze. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Due to Entering Blind Alleys. | | | | Movements in the Right Path but in the Wrong Direction. | Total. | The Number of Times it Rushed into the Water Before Beginning to Run the Maze. | The Number of Times it Fell into the Water After Beginning to Run the Maze. | The Number of Times it Jumped into the Water. | Total. | | |
| | | I. (Fig. 1, *A*.) | II. (Fig. 1, *B*.) | III. (Fig. 1; 8, *D*, *E*.) | IV. (Fig. 1; 9, 10, 11, *F*, *G*.) | | | | | | | | |
| 1 | 0 | 2 | 0 | 2 | 0 | 18 | 22 | 2 | 3 | 1 | 6 | 13 | 37 |
| 2 | 18¼ | 2 | 0 | 3 | 1 | 9 | 15 | 1 | 1 | 2 | 4 | 6 | 27 |
| 3 | 16 | 2 | 0 | 1 | 0 | 10 | 13 | 2 | 2 | 1 | 5 | 7 | 23 |
| 4 | 16½ | 1 | 0 | 1 | 0 | 6 | 8 | 0 | 1 | 1 | 2 | 7 | 26 |
| 5 | 11½ | 0 | 0 | 1 | 1 | 6 | 8 | 0 | 0 | 0 | 0 | 4 | 17 |
| 6 | 5 | 1 | 0 | 1 | 0 | 7 | 9 | 0 | 1 | 0 | 1 | 3 | 12 |
| 7 | 4½ | 1 | 0 | 2 | 0 | 7 | 10 | 1 | 1 | 0 | 2 | 9 | 13 |
| 8 | 1½ | 0 | 0 | 1 | 0 | 2 | 3 | 1 | 2 | 0 | 3 | 5 | 10 |
| 9 | 9½ | 1 | 0 | 0 | 0 | 9 | 10 | 0 | 2 | 0 | 2 | 2 | 11 |
| 10 | 3¼ | 1 | 0 | 0 | 0 | 6 | 7 | 0 | 2 | 2 | 4 | 7 | 11 |
| 11 | 1 | 1 | 0 | 0 | 1 | 2 | 4 | 0 | 1 | 1 | 2 | 4 | 12 |
| 12 | 1 | 1 | 0 | 0 | 0 | 6 | 7 | 0 | 0 | 0 | 0 | 2 | 5 |
| 13 | 1¼ | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 5 |
| 14 | 1 | 0 | 0 | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 3 |
| 15 | 1 | 1 | 0 | 1 | 0 | 1 | 3 | 1 | 0 | 0 | 1 | 3 | 3 |
| 16 | ¾ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 4 |
| 17 | ¾ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 5 |
| 18 | ½ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 5 | 2 |
| 19 | ½ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 4 |
| 20 | ½ | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 4 |
| 21 | ½ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 |

This table records the reactions of a young female roach 17 mm. long. Throughout the first part of the series the rest period between two trials was long.

## TABLE IV.

| Successive Trials. | Date. | Number of Hours that Have Elapsed Since the Beginning of the Last Trial. | Errors Due to Movements on the Maze. | | | | | | Errors which Caused the Roach to Fall into the Water. | | | | Total Minutes Required to Run the Maze. | The Number of Times it Stopped to Make its Toilet. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Due to Entering Blind Alleys. | | | | Movements in the Right Path, but in the Wrong Direction. | The Number of Times it Rushed into the Water Before Beginning to Run the Maze. | The Number of Times it Fell into the Water After Beginning to Run the Maze. | The Number of Times it Jumped into the Water. | Total. | The Number of Times it Stopped to Make its Toilet. | | |
| | | | I. (Fig. 1, *A*.) | II. (Fig. 1, *B*.) | III. (Fig. 1; 8, *D*, *E*.) | IV. (Fig. 1; 9, 10, 11, *F*, *G*.) | | | | | | | | |
| 1 | Aug. 8, 9:13 A.M. | 0 | 0 | 0 | 1 | 0 | 13 | 14 | 1 | 2 | 2 | 5 | 9 | 14 |
| 2 | Aug. 9, 8:19 A.M. | 23 | 1 | 0 | 1 | 1 | 5 | 8 | 1 | 2 | 1 | 4 | 6 | 26 |
| 3 | Aug. 9, 1:43 P.M. | 5½ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 3 |
| 4 | Aug. 10, 6:57 A.M. | 17¼ | 1 | 0 | 1 | 0 | 9 | 11 | 0 | 3 | 3 | 6 | 18 | 57 |
| 5 | Aug. 10, 11:18 A.M. | 4¼ | 0 | 0 | 1 | 0 | 5 | 6 | 0 | 0 | 0 | 0 | 2 | 21 |
| 6 | Aug. 10, 2:52 P.M. | 3½ | 1 | 0 | 0 | 0 | 8 | 9 | 0 | 1 | 0 | 1 | 1 | 11 |
| 7 | Aug. 10, 4:26 P.M. | 1½ | 2 | 0 | 3 | 0 | 17 | 22 | 1 | 0 | 0 | 1 | 23 | 22 |
| 8 | Aug. 10, 6:30 P.M. | 2 | 1 | 0 | 1 | 0 | 6 | 8 | 0 | 0 | 0 | 0 | 3 | 6 |
| 9 | Aug. 11, 5:40 A.M. | 11¼ | 1 | 0 | 1 | 0 | 13 | 15 | 0 | 0 | 0 | 0 | 3 | 18 |
| 10 | Aug. 11, 7:00 A.M. | 1¼ | 1 | 0 | 1 | 0 | 7 | 9 | 0 | 1 | 1 | 2 | 5 | 12 |
| 11 | Aug. 11, 8:23 A.M. | 1½ | 3 | 0 | 1 | 1 | 13 | 18 | 2 | 0 | 2 | 4 | 10 | 23 |
| 12 | Aug. 11, 10:54 A.M. | 2½ | 2 | 0 | 1 | 0 | 5 | 8 | 0 | 0 | 0 | 0 | 5 | 7 |
| 13 | Aug. 11, 1:23 P.M. | 2½ | 0 | 0 | 1 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 7 |
| 14 | Aug. 11, 2:00 P.M. | ½ | 1 | 0 | 1 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 2 | 2 |
| 15 | Aug. 11, 2:29 P.M. | ½ | 0 | 1 | 1 | 0 | 5 | 7 | 0 | 0 | 0 | 0 | 3 | 5 |
| 16 | Aug. 11, 3:12 P.M. | ¾ | 1 | 0 | 1 | 0 | 8 | 10 | 0 | 0 | 0 | 0 | 1 | 7 |
| 17 | Aug. 11, 3:46 P.M. | ½ | 0 | 0 | 0 | 0 | 8 | 8 | 0 | 0 | 0 | 0 | 1 | 9 |
| 18 | Aug. 11, 4:37 P.M. | ¾ | 1 | 0 | 1 | 0 | 5 | 7 | 0 | 0 | 0 | 0 | 2 | 2 |
| 19 | Aug. 12, 6:02 A.M. | 13½ | 1 | 0 | 1 | 0 | 7 | 9 | 0 | 0 | 0 | 0 | 6 | 22 |
| 20 | Aug. 12, 6:30 A.M. | ½ | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 4 | 0 | 4 | 3 | 12 |
| 21 | Aug. 12, 6:56 A.M. | ½ | 1 | 0 | 1 | 0 | 2 | 4 | 0 | 4 | 0 | 4 | 6 | 13 |

This table records the reactions of a female roach 10 mm. long which after 21 trials had displayed no ability to learn the maze. It learned to avoid falling into the water; but displayed no ability to avoid making errors on the runways. It finally gave up attempting to learn the maze and tried to jump to freedom. The roach was accidentally killed at the close of the 21st experiment. Its reactions are recorded because it was the most unapt roach that I had.